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Ions produced by X-rays in the air at atmospheric pressure

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With 15 figures in the text

1. Introduction

Ions generated by a number of sources have been investigated at this Institute during the last few years [6, 7, 8, 11]. For another investigation the Institute had at its disposal an X-ray impulse lamp designed for use of dentists and the opportunity was taken to investigate the ions produced by this ion source. The concentration and mobility spectra of small and large ions generated by X-rays from the lamp were measured to complete the previous investigations carried out at this Institute on ions from the other sources.

X-rays are known for a long time to be an effective ionisator and are often used as ion source for many experiments. It is generally assumed that they give us only small ions of both signs and with mobilities about 1 cm/sec:volt/cm. Not much has been done to explore X-ray ions since the pioneering work done on them at the beginning of this century. Recently Pollermann [9] has used them to explore condensation processes around ions in a cloud chamber.

Measurements carried out at the Institute on small ions in the atmospheric air enriched with the air from the ground [12] showed the existence of two different mobility groups of small ions. Yunker [18] has found the same for atmospheric small ions. That artificial ions can also have several groups of mobility has been indicated by Erikson [2], Zeleny [17]; Chapman [1]. It is of interest to see if the X-ray small ions have two groups or only one group of mobility for each sign of ions. If there are several groups, then the process of transformation is very important. The next question is whether X-rays are able to create condensation nuclei and large ions, or whether the X-rays ionize the already existing nuclei and in such a way increase the amount of large ions.

2. Apparatus

The X-ray lamp was a Siemens "Röntgenkugel" R 305/4263, designed for use of dentists. Therefore uninterrupted X-raying with it was not possible. One could obtain at most a single flash per minute of a maximum duration of 5 seconds. The common procedure of measuring, that is that of switching on the ion source, measuring the number of ions and their spectrum during the course of time, had to be modified. Apart from this, the apparatus and the method of counting remained the same as when measuring corona ions [6].

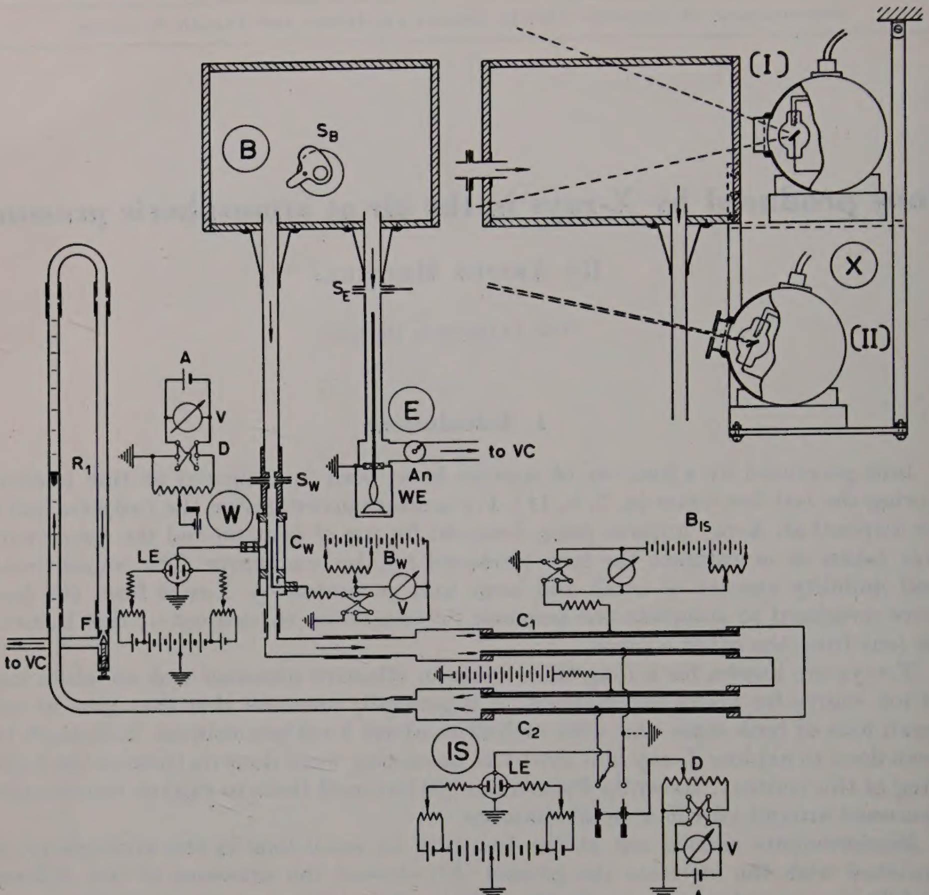

Fig. 1. Schematic diagram of the experimental arrangement. (B) suction-box; S_B inlet-tube with slide, S_E and S_W slides to ion counters. (W) small-ion counter with Weger condenser C_W; Lindemann electrometer LE, calibration device D, potential for control electrode B_W. (IS) Israël large-ion counter; C_1, C_2 cylindrical condensers with batteries B_{IS}; LE Lindemann electrometer with calibration device D; R rotameter; VC vacuum cleaner. (X) X-ray lamp in position (I) X-raying the suction-box B and in position (II) X-raying only the suction tube to the ion counters.

Ions were generated by X-raying the air in the suction-box. The wooden walls of the box permitted sufficient X-rays to ionize the air in the suction-box giving an ion concentration of c. $10^6\ n/\mathrm{cm}^3$, so that it was necessary to diminish the X-ray intensity by absorbing them in some mm of iron sheet. The arrangement is shown in Fig. 1.

The small ions were measured with a counter built at the Institute and containing a Weger condenser [10]. The large ions were counted with the Israël large-ion counter [6], connected in series with the small-ion counter, which caught all ions with a mobility greater than c. 0.15 cm/sec:volt/cm.

A vacuum cleaner supplied a constant airflow ϕ through the counter and the suction-box and this ϕ was measured with a rotameter. The inlet of the suction-box was connected to a test-room which had been used previously in ion measurements at the Institute [6].

3. Procedure of measurements

As already stated it was not possible to use the usual procedure—to measure the change of ion concentration with time after switching on the ion source, to do this with different potentials V at the control electrodes, or at different limiting mobilities, and to determine the ion spectra from the curves obtained, especially when the ion concentration reaches some equilibrium.

The suction-box was X-rayed instead of X-raying and ionizing the air in the test-room and in this way the following advantages were obtained: (1) the beam of X-rays covered all the suction-box, but it could not cover all the test-room; (2) the path of ions from their origin to the counter was thus shortened and the losses of ions through recombination, combination and absorption in the connection pipes to the ion counters were decreased.

As the lamp gives only X-ray flashes, the constancy of their intensity has to be investigated first of all. The following factors must be considered:

(1) The duration of X-ray flash. The switching watch of the X-ray lamp can be adjusted to an accuracy of $\leq 1\%$ when taking flashes of two seconds' length or longer. If the motion of the watch itself is accurate within the same possible error, then the length of a single flash is accurate to $\sim 1\%$.

(2) The voltage changes in the net. The high tension applied to the X-ray lamp depends on net voltage and its changes, and this determines the hardness of the X-rays. The intensity of the X-rays also depends on the net voltage. To detect this influence measurements on the number of small ions were carried out when the net was differently loaded. It was found that the ion concentration changed by about 4% when the net voltage itself was varied by 1 volt, the net tension being between 210–230 V. A stabilizer was necessary in order to avoid the changes of the net voltage, but those at our disposal could not hold the c. 1 kw load when switching on the X-ray lamp. Therefore when working the net was loaded with a resistor in parallel with the X-ray lamp and by changing this resistance the voltage of the net was kept constant to within ± 0.5 volt. At least two measurements were always taken for each limiting mobility of the counter and when these two disagreed, an additional third reading was taken.

(3) The constant action of the lamp itself during flashes. After eliminating possible errors under the above two heads the agreement between single measurements was consistent to within a few per cent. Therefore the operation of the lamp itself satisfied the requirements of the experiment.

The individual flashes took place at regular time intervals, usually 5 minutes. During this time the ion concentration, because of recombination and replacing of the air in the suction-box, had practically reached the background level again, namely that determined by natural ionization.

The time t when the needle of the electrometer passed some fixed number on the scale divisions was read off at the beginning of the measurements, but soon it was found to be much better to take the electrometer readings at certain fixed whole seconds which were followed in the head telephone connected with a clock, so that one had only to watch the electrometer readings. In this way time was measured

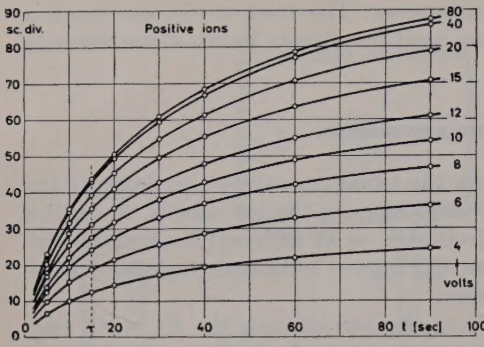

Fig. 2. $\bar{n} = \psi(t; k_*)$ curves for positive small ions from X-ray flashes, measured in scale divisions of the electrometer.

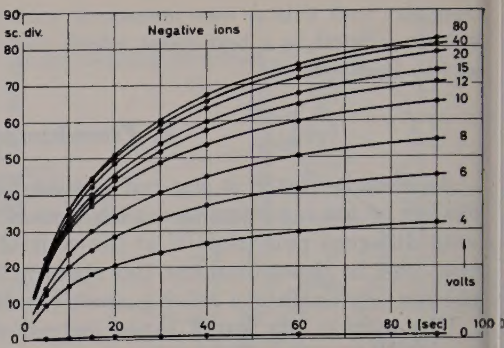

Fig. 3. $\bar{n} = \psi(t; k_*)$ curves for negative X-ray small ions, measured in scale divisions of the electrometer.

more accurately than with a watch. For example, the readings were done at $t = 0$ sec., that is at the starting moment of the flash and then at $t = 5$, 10, 15, 20, 30, 40, 60 and 90 sec.

4.1. Evaluation of measurements

The measurements give the total number $\bar{n}$ of ions which reach the counter and are captured during a definite time interval from the beginning of the X-ray flash. And for an X-ray flash of a definite length and intensity this $\bar{n}$ depends on the tension applied to the control electrode of the ion counter; it corresponds to a definite limiting mobility k_*. By repeating this for a series of limiting mobilities a family of curves is obtained some of which are plotted in Figs. 2 and 3. Each curve represents

$$\bar{n} = \int_0^t \phi\, n\, dt = \phi \int_0^t \int_{k_*}^{\infty} f(k, t)\, dk\, dt + \frac{\phi}{k_*} \int_0^t \int_0^{k_*} k\, f(k, t)\, dk\, dt \tag{1}$$

or $\bar{n} = \psi(t; k_*)$, i. e. the total number of counted ions as a function of time and containing different counter-limiting mobilities k_* as parameter where the air-flow ϕ remains constant.

The expression for the ion concentration n measured at a definite limiting mobility of the counter is as usual [13]

$$n = \int_{k_*}^{\infty} f(k, t)\, dk + \frac{1}{k_*} \int_0^{k_*} k\, f(k, t)\, dk = n(k_*, t) \tag{2}$$

with the sole difference that the function of occupation—$f(k)$ itself is taken as dependent on the time—$f(k, t)$.

Taking some definite time moment $t = \tau$, e.g. $t = 15$ sec. and by differentiating the $\bar{n} = \psi(t; k_*)$ curves at this point, n values are obtained for different chosen limiting mobilities defined by the tension of the control electrode. When n values are found the characteristics may be drawn as usual [13]—the direct $n = \varphi(k_*)$ or the reciprocal

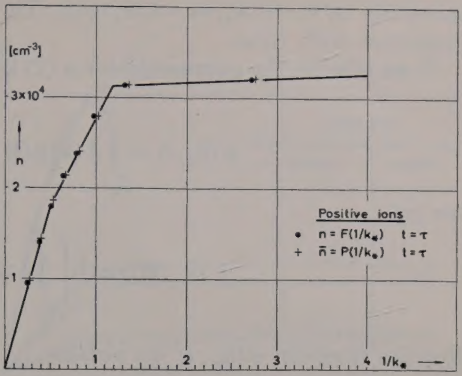

Fig. 4. $1/k_*$ characteristic for positive ions deduced both from n- and from the $\bar{n}$-curves for the same time moment $t = \tau$.

$n = F(1/k_*)$ for definite $t = \tau_i$ values. Without performing this mathematical operation we have to write characteristics in the form $n = \varphi(k_*, t)$ or $n = F(1/k_*, t)$.

As we will see later, it is sometimes possible to take the measured values $\bar{n}$ instead of n, for they are both directly proportional to one another under certain conditions. That these conditions are fulfilled in the present measurements is seen from Fig. 4, in which two curves are shown, one based on the values of n and the other on the values of $\bar{n}$ directly choosing the proper scale in both cases.

4.2. $\bar{n} = \psi(t; k_*)$ curves

When we use the actual measured values of $\bar{n}$ as ordinates we get a family of curves expressed by the relation $\bar{n} = \psi(t; k_*)$. On the other hand, we cannot obtain directly n-curves, which are known in ion measurements as the characteristics, by plotting the measured values. To obtain the points for these n-curves we must calculate the values $(d\bar{n}/dt)_{t=\tau_i}$, i.e. we must take the slopes of the family of $\bar{n}$-curves for fixed values $t = \tau_i$. We can then plot the family of n-curves in either of the two forms—$n = \varphi(k_*)$ or $n = F(1/k_*)$—choosing that form which is most suitable for our purposes. If the measured values $\bar{n}$ are to be used to obtain the characteristics directly, there must exist proportionality

$$n_1 : n_2 : n_3 : \qquad = \bar{n}_1 : \bar{n}_2 : \bar{n}_3 :$$

or

$$\varphi(k_1) : \varphi(k_2) : \varphi(k_3) : \; = \psi(k_1) : \psi(k_2) : \psi(k_3) :$$

or

$$\frac{\varphi(k_1)}{\psi(k_1)} = \frac{\varphi(k_2)}{\psi(k_2)} = \frac{\varphi(k_3)}{\psi(k_3)} = \cdots = \text{const.} \tag{3}$$

for

$$t = \tau_1, \tau_2, \tau_3 \ldots$$

If the ion spectrum does not cover a wide range of mobility Δk, it may be assumed that all the ions in this range have the same coefficient of recombination and the same coefficient of combination with large ions, that is, all ions in this mobility interval Δk have the same properties and physical constants. If this assumption is true then the entire ionic spectrum will obey a law which may be expressed mathematically as $n = n(k_*, t) = h(k_*)\, g(t)$. The function $g(t)$ gives the change of the ionic spectrum with time.

If we rewrite the expression for n (2) in its new form

$$n(k_*, t) = \int_{k_*}^{\infty} h(k)\, g(t)\, dk + \frac{1}{k_*} \int_{0}^{k_*} k h(k)\, g(t)\, dk$$

we get

$$\varphi(k_*, t) = g(t) \left[\int_{k_*}^{\infty} h(k)\, dk + \frac{1}{k_*} \int_{0}^{k_*} k\, h(k)\, dk \right]. \tag{4}$$

For the function $\psi(k_*, t)$ we obtain

$$\psi(k_*, t) = \phi \int_{0}^{t} n(k_*, t)\, dt = \phi \int_{0}^{t} g(t)\, dt \left[\int_{k_*}^{\infty} h(k)\, dk + \frac{1}{k_*} \int_{0}^{k_*} k\, h(k)\, dk \right]. \tag{5}$$

From (4) and (5)

$$\frac{\varphi(k_i)}{\psi(k_i)} = \frac{g(t)}{\phi \int_{0}^{\tau_t} g(t)\, dt} = \text{const.} \tag{6}$$

The ratio (6) is independent of k_i for fixed $t = \tau_t$.

Thus it is shown that under the conditions mentioned such interchange of n and $\bar{n}$ is permissible. Such interchanges were often used when evaluating the measurements, especially when there was some doubt how to draw the curves through the points obtained in the ordinary way, that is, when it was impossible to say if there was only one break in the $n = F(1/k_*)$ curves or more breaks.

5. Results

5.1. Small ions

The small ions constitute the bulk of the ions generated by X-rays. As will be seen later the amount of large ions generated is very small, being only a few per mil of the number of small ions. It may be questioned whether they are generated immediately or are a later product of transformation.

The concentration of small ions is approximately the same for positive and negative ones, that of the positive ions being a little larger (Figs. 5 and 6). The maximum of the absolute difference $n_+ - n_-$ occurs some 10–20 seconds after the flash, but the relative maximum n_+/n_- occurs only after 2–3 minutes (Fig. 7). This is explainable by the different mobilities of positive and negative ions, negative ions being more mobile. Therefore they diffuse faster towards the walls of the suction-box and connecting pipes. Consequently more of them are adsorbed there than of the positive ions, the latter attaining a small surplus in this way.

In general positive small ions have two groups which have not a very stable position in the mobility spectrum but may shift themselves a little to one side or the

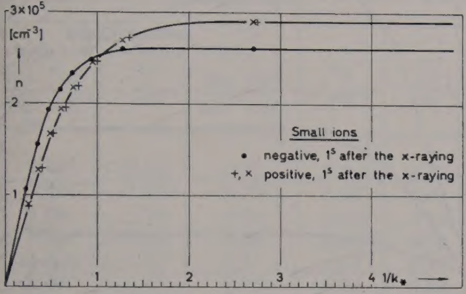

Fig. 5. $1/k_*$ characteristics for X-ray small ions.

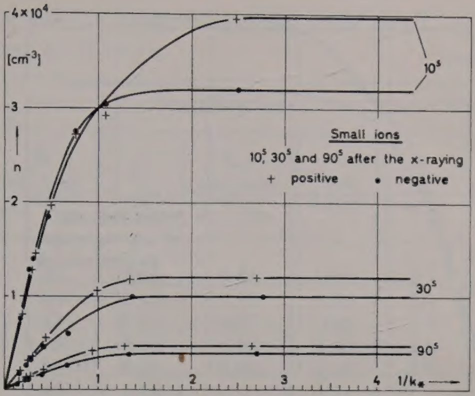

Fig. 6. $1/k_*$ characteristics for X-ray small ions for different $t = \tau_i$.

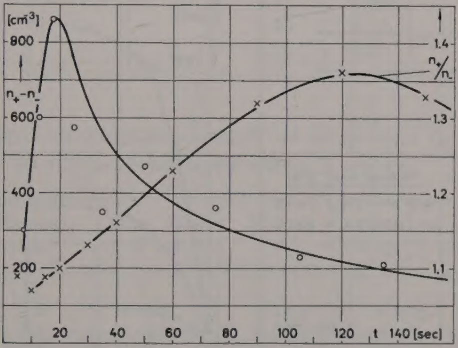

Fig. 7. The $n_+ - n_-$ and n_+/n_- curves of X-ray small ions as functions of time.

other. The largest group, containing about $\frac{2}{3}$ of all the positive ions, lies commonly in the range $k_2 = 0.6$–0.9 cm/sec:volt/cm, but the remaining portion lies between 1.3 and 2.2 cm/sec:volt/cm (Table 1). These two groups are seen on $1/k_*$ characteristics as distinct breaks. In some few cases one break only is to be found and the ion group associated with this break occupies a broader region of the mobility spectrum than in the two group cases. Fig. 8 may be cited as an example of a typical characteristic of positive small ions generated by X-rays; other examples are shown in Fig. 9. The mobility range in these examples is $k = 1.0$–1.1 cm/sec:volt/cm showing that this group has the same mobility range as the positive small atmospheric ions [4].

On the other hand, the negative small ions are seen generally to form only one group having a mobility between $k_1 = 0.9$–1.5 cm/sec:volt/cm. Sometimes they form two groups. In such cases, one group containing about $\frac{3}{4}$ of all the negative small ions has a mobility range $k_1 = 1.0$–1.6 cm/sec:volt/cm and the other smaller group $k_2 = 0.7$–1.0 cm/sec:volt/cm (Table 1).

In exceptional cases, when the group $k_2 = 0.7$–1.0 cm/sec:volt/cm is not present, another group in the range $k_3 = 2.5$–3.0 cm/sec:volt/cm is found containing 10 % of

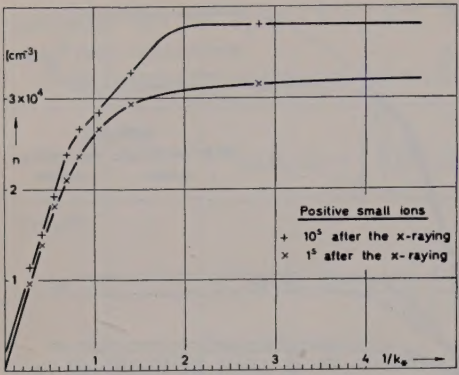

Fig. 8. $1/k_*$ characteristics of X-ray positive small ions.

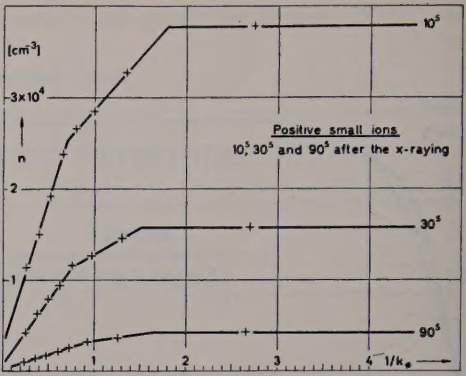

Fig. 9. $1/k_*$ characteristics of X-ray positive small ions.

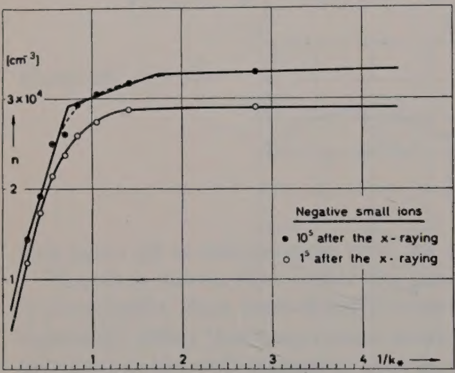

Fig. 10. $1/k_*$ characteristics for X-ray negative small ions.

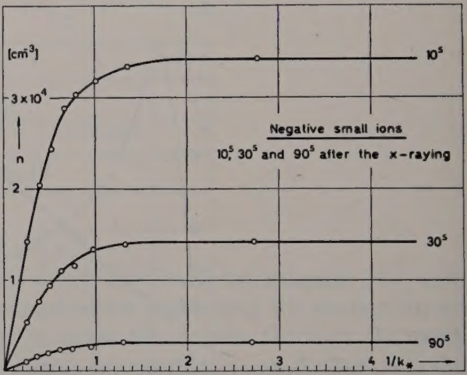

Fig. 11. $1/k_*$ characteristics for X-ray negative small ions.

the negative small ions. Fig. 10 is an example of a characteristic for negative small ions. Other examples are given in Fig. 11.

5.2. *Large ions*

By directly measuring the large ions with an Israël large-ion counter no increase in concentration after the X-ray flash could be detected. As the undisturbed concentration (background) of the large ions was very low (only 100–200 N/cm^3), it was impossible to make sufficiently exact measurements. But we can state that if large ions are generated these do not exceed some per mil of the number of small ions.

5.2. *The transformation of ions*

The following experiment was carried out to see if the increase of small ions influences the already existing large ions and, if it does, to find out the extent of this influence. Ultra-violet light was switched on in the test-room giving a mixture of ions both large and small and of condensation nuclei [8]. After about an hour, when

Table 1. The average mobility k and the size of positive and negative small-ion groups n produced by X-rays.

Positive ions					Negative ions				
k_1 $\frac{\text{cm}}{\text{sec}}:\frac{\text{volt}}{\text{cm}}$	n_1 $\times 10^{-4}$	k_2 $\frac{\text{cm}}{\text{sec}}:\frac{\text{volt}}{\text{cm}}$	n_2 $\times 10^{-4}$	$\frac{n_1}{n_2}$	k_1 $\frac{\text{cm}}{\text{sec}}:\frac{\text{volt}}{\text{cm}}$	n_1 $\times 10^{-4}$	$k_{2,3}$ $\frac{\text{cm}}{\text{sec}}:\frac{\text{volt}}{\text{cm}}$	$n_{2,3}$ $\times 10^{-4}$	$\frac{n_1}{n_{2,3}}$
1.96	0.83	0.85	2.24	0.37	1.35	2.65	0.58	0.65	4.1
1.35	1.69	0.53	1.93	0.87	1.54	2.42	0.82	0.85	2.8
1.39	1.74	0.56	2.06	0.84	1.43	1.60	0.77	0.60	2.7
1.30	0.70	0.66	0.88	0.79	1.23	3.10	2.86	0.35	8.8
1.85	1.62	0.71	2.08	0.78	1.49	3.20	2.63	0.40	8.0
2.08	0.45	0.76	1.35	0.33	1.45	4.00			
1.96	0.15	0.62	0.32	0.47	1.56	1.47			
1.02	3.15				1.49	3.42			
1.06	3.96				1.41	1.42			
1.02	1.20				1.37	0.31			
1.19	2.90				1.41	2.90			
1.06	4.00				1.43	3.20			
1.04	1.71				1.15	0.39			

Table 2. The increase in the concentration N of large ions in air formerly exposed to ultra-violet light when X-rayed.

Before N_+	X-rayed N_+	Increase %	Max. after T sec	Before N_-	X-rayed N_-	Increase %	Max. after T sec
9 500	10 100	8	66	6 750	8 000	16	39
8 950	9 800	12	60	7 050	8 000	13	36
8 450	8 950	9	78	7 050	7 800	11	56
6 950	8 200	18	64	6 900	8 700	26	35

the ion mixture had attained some state of equilibrium, measurements were begun. First the number of large ions at different limiting mobilities was measured and in this way the characteristic for large ions from ultra-violet light was obtained. Then the suction-box was X-rayed when full air-flow ϕ from the test-room was sucked through it and the same measurements were again carried out. As a result of the X-ray flash the concentration of the large ions in this air was found to increase temporarily by about 10–20 %, returning later to its original level. This increase occurred sooner for negative large ions. For these the number of ions reached its maximum in ca. 40 seconds, while positive large ions proceeded to increase for about 65 seconds, Table 2.

The first N_+ and N_- give the numbers of large ions before the X-ray flash, and the second after the X-ray flash. "%" gives the relative increase after the flash. T sec indicates the time in which the maximal value of N_+ or N_- was reached after the flash. All N_+ and N_- in Table 2 are measured at $k_* = 0.0027$ cm/sec:volt/cm.

Such numbers as stated in % and T sec columns in Table 2 depend not only on the laws of recombination and combination, but also on the apparatus (suction-box,

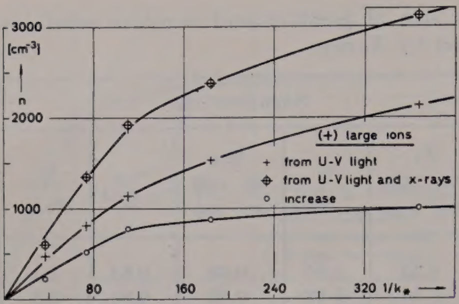

Fig. 12. $1/k_*$ characteristics for positive large ions.

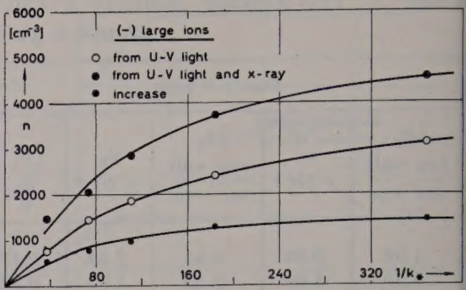

Fig. 13. $1/k_*$ characteristics for negative large ions.

pipes, air-flow etc.) and the condition of the air (humidity, temperature etc.). Figs. 12 and 13 are examples of large ion measurements. The characteristic of the large ions is only slightly modified by the X-ray flash. It retains its former form, showing that even spectral distribution of the large ions has been little changed. The lighter-ion part of the spectrum shows the largest increase. If the spectrum of the difference of X-rayed large ions and non-X-rayed large ions is definite enough, then the conclusion can be drawn that the small ions attach themselves to the smaller nuclei generating ions with a mobility $k = 0.01$–0.02 cm/sec:volt/cm, that is, ions classified as intermediate ions.

With such measurements it would be possible to follow the process of ionic transformation, but in practice it is difficult to measure two characteristics with sufficient precision. Hence it is not possible to rely on the difference of two characteristics when taken as a new characteristic for itself.

5.4. Small ions in the atmosphere of large ions

What happens to small ions when they are generated in a space filled with large ions and nuclei? The characteristics for the X-ray small ions are drawn, both before and during the generation of large ions, by irradiation of the space with ultra-violet light. The result is shown in Fig. 14. The number of large ions is increased by the ultra-violet light and therefore the X-ray small ions have a greater probability of combining with large ions to give neutral nuclei. Two other processes occur with increased intensity: the combination of small ions with nuclei to form large ions, and

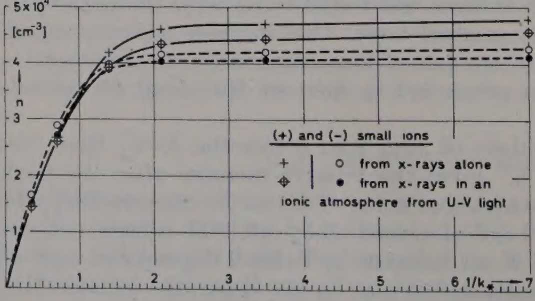

Fig. 14. $1/k_*$ characteristics for X-ray small ions and for the same ions when in the atmosphere of the ions generated by ultra-violet light.

secondly the recombination between positive and negative small ions. The result is a decrease of the concentration of the small ions.

But the form of the characteristic remains the same as before, only the general level of small ion concentration having decreased a little. This means that the mobility spectrum of small ions has not changed. The level of concentration of small ions may sink and if this happens that of the large ions will increase. The measured changes are equal and opposite—at least within the limits of experimental error.

5.5. *The n curves obtained by zero volt at the control electrode of the counter*

Carrying out the measurements for small ions with different tensions applied to the control electrode of the small ion counter zero voltage was tentatively applied. One of the curves obtained is shown in Fig. 15. It was found that the condenser acquired a small negative charge which can be explained by ion absorption in the counter. For ion adsorption cf. Zeleny [16], Villari [15], Siksna and Metnieks [14].

When ions of both signs and of approximately the same concentration are present, the observed negative charging of the condenser when no voltage is applied can be explained only by the greater mobility of the negative small ions. The charging rate decreases with time, because the concentrations of ions of both signs decrease as a result of recombination. After about a minute there is no longer any charging effect. Then it changes its sign and the charging becomes positive. Two different assumptions might be adduced to explain such behaviour of the small ions:

(1) The concentration of the negative ions is too low in relation to that of the positive ions at the time of transition of polarities, or

(2) the negative small ions have changed their mobility more than the positive ions and are now as slow as, or even slower than, the positive ones.

To decide between these alternatives some additional measurements were made. The concentration of ions of both signs was measured carefully and the changes of concentrations with time were especially noted. The curves obtained are shown in Fig. 15.

During the whole experiment the concentration of the positive ions exceeds that of the negative ions. Therefore the first part of the curve—the negative charging of the condenser—is due to the greater mobility of the negative ions.

The concentrations of both ions decrease after the X-ray flash has ended, but the

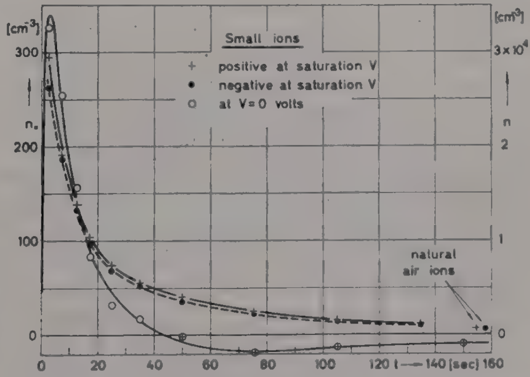

Fig. 15. The counted numbers of positive and negative X-ray small ions n at saturation voltage at the control electrode and the counted numbers n_0 at potential 0 volts.

number of the negative ions decreases more rapidly; correspondingly the ratio of the positive and negative small ions increases with time. It is difficult to judge from the obtained curves alone if these changes of ion concentrations are sufficient to explain the following positive charging of the condenser, because there is no acceptable theory from which to calculate the charging of an insulated body by adsorption of ions. As no mobility shift of the negative small ions to the slower side of the ion spectrum can be observed, the positive charging of the ion counter exhibited in the latter part of the curves must be attributed to the increasing surplus of the positive ions.

6. Some considerations regarding the mobility distribution of atmospheric small ions

Loeb [5] does not admit the existence of more than two small ion groups and thinks that even these two groups may exist simultaneously only under extraordinary conditions as, for example, in Chapman experiments [1]. The first of these two groups is not stable and by ageing goes over into the second. This change takes place in a single step and occurs in time of the order of 10^{-2} seconds or less, so that thereafter only one form of the ions is present. If this hypothesis is correct, then the two groups observed during the interval 5 to 60 seconds after the small ions have been generated by X-ray flashes cannot both be real and one of them must be only apparent.

Pollermann [9], while investigating the formation of droplets around positive and negative ions, measured the mobility of these ions in saturated and in supersaturated air. He also found only one mobility group for negative small ions, but two groups for positive small ions the mobilities of which differ little. For example, in the case of twofold supersaturation the mobility for the first group was $k = 0.9$ and for the other $k = 1.1$ cm/sec:volt/cm.

As shown by other investigations at this Institute [12] there exist several kinds of small ions and at times it is necessary to point out very exactly which small ions are in question. We agree that in normal atmospheric air atomic and molecular ions are produced by ionization, and that in a very short interval, 10^{-2} sec. or less, cf. above, these change into the initial small ions—these latter already being in the form of clusters. The clusters may sometimes undergo further changes to become affected small ions after some time. These latter are stable and can only recombine with other small ions or combine with either large ions or condensation nuclei. They do not, however, continue to increase steadily in volume.

Hogg [3] has found ions in atmospheric air with a mobility varying between $k = 0.02$ cm/sec:volt/cm and $k = 0.001$ cm/sec:volt/cm. He attributed them to the droplets of sulphuric acid. Such ions correspond to those mentioned in 5.3, above, which had a mobility $k = 0.01$–0.02 cm/sec:volt/cm and which gave the increase of large ions when X-rayed. But it is not very likely that they could be the X-ray small ions transformed in the meantime to such a low mobility. There is no indication that the small ions transform themselves directly to a mobility lower than ca. $k = 0.5$ cm/sec:volt/cm. Therefore, there must exist a small amount of condensation nuclei of such magnitude that by combining with small ions they give such intermediate ions.

Summary

Small ions formed in the atmospheric air by X-rays are measured. Ions of both signs are produced with approximately the same abundance. Frequently two groups with different mobilities have been found, especially in the case of positive ions.

It is found that practically no large ions are generated by X-rays, but when the atmosphere already contains large ions, X-raying increases their concentration by 10–20 % on account of the uncharged part of the nuclei.

Conditions are discussed under which it is permissible to interchange n-values and $\bar{n}$-values when drawing characteristics, that is, interchanging the instantaneous ion concentration and its accumulative value.

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REFERENCES

1. Chapman, S., Interpretation of carrier mobility spectra of liquids electrified by bubbling and spraying. *Phys. Rev., 57,* 528–533, 1938.
2. Erikson, H. A., Factors affecting the nature of ions in air. *Phys. Rev., 34,* 635–643, 1929.
3. Hogg, A. R., The intermediate ions of the atmosphere. *Proc. Phys. Soc., 51,* 1014, 1939.
4. Israël, H., Luftelektrizität, *in* Landolt–Börnstein, Zahlenwerte und Funktionen, 6. Aufl. *Bd. 3,* p. 711. Berlin–Göttingen–Heidelberg: Springer-Verlag, 1952.
5. Loeb, L. B., Fundamental Processes of Electrical Discharge in Gases, pp. 40, 47. New York, 1939.
6. Norinder, H., and Siksna, R., Ions formed in a room by negative wire corona. *Ark. Fys., 6,* 127–140, 1952.
7. —— Ions formed in a room by positive wire corona. *Ark. Fys., 6,* 255–261, 1953.
8. —— Ions produced in the air at atmospheric pressure by ultra-violet light from a quartz–mercury arc. *Ark. Fys., 5,* 471–491, 1952.
9. Pollermann, M., Die Tröpfchenbildung an Ionen in der Wilsonschen Nebelkammer. *Ann. Physik,* 6. Folge, *5,* Nr. 6–8, 329, 1950.
10. Siksna, R., Mobility spectra of ions formed by positive corona discharge. *Ark. Fys., 6,* 279–286, 1953.
11. —— Positive ions formed by an open electric heater. *Ark. Fys., 5,* 531–543, 1952.
12. —— Mobility of small atmospheric ions in the air from the ground at Uppsala. *Journ. Atmos. Terr. Physics, 4,* 106–111, 1953.
13. —— Measurements of large ions in the atmospheric air at Uppsala. *Ark. Geofys., 1,* 483–518, 1952.
14. Siksna, R. und Metnieks, A., Aufladung eines isolierten Rohrs bei Durchströmen von ionisierter Luft und Absorption der Ionen. *Z. angew. Phys., 5,* 454–461, 1953.
15. Villari, E., Wie die X-Strahlen durchsetzte Luft ihre entladende Kraft verliert and wie sie Ladungen mit hohen Potentialen entwickelt. *Phys. Z., 2,* 178–180, 1900.
16. Zeleny, J., Über die von Röntgenstrahlen ausgesetzten Gasen hervorgerufene Elektrisierung. *Phys. Z., 4,* 667–675, 1903.
17. —— The distribution of mobilities of ions in moist air. *Phys. Rev., 34,* 310–334, 1929.
18. Yunker, E. A., The mobility-spectrum of atmospheric ions. *Terr. Magn., 45,* 127–132, 1940.

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